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A new concept of positioning system for an end-station of the recently upgraded beamline ID24

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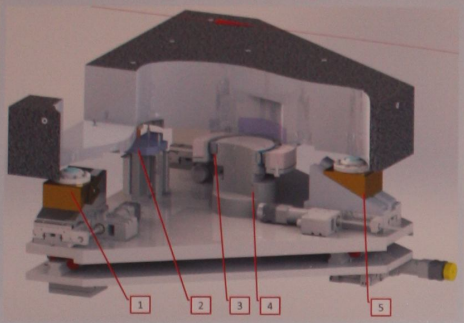
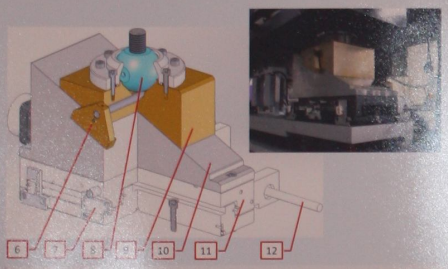
Introduction : A new positioning system concept has been designed for an end-station of the recently upgraded ID24 beamline. This end-station is dedicated to in-situ High-Pressure and High-Temperature (HP-HT) experiments using energy dispersive X-ray absorption spectroscopy technique with a micrometer sized X-ray beam. It will serve the ID24 geochemistry and geophysics user community and be used for studies on molten metals, reactions at extreme conditions, material synthesis etc. (deep-Earth materials and other phases containing iron, cobalt, nickel, copper, manganese and other elements).
The particularity of the HP-HT end-station from a mechanical point of view is its 5-axis positioning system for a quite large optic setup, which of 3 axis (Tz, Rx, Ry) are performed using a new kind of tripod designed to optimise the vibration stability. Indeed, in order to achieve the specifications required in terms of positioning stability and to accommodate the interfacing requirements with the beamline environment, we chose to design a specific mechanical architecture limiting the stacking of roller based guides. Design, calculations and measurements are detailed in this poster.

The Tripod with sliding wedges actuators



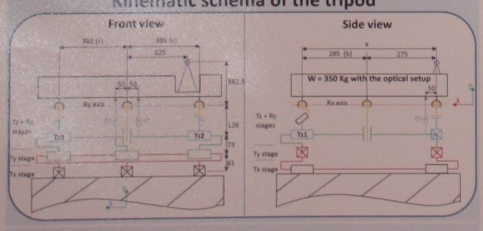
1: Tz actuator with sliding flat wedge
2: Three digital length gauges for the positioning optimisation
3: Barrel roller bearing for ball joint of the central guiding
4: Ball bushing of the central guiding
5: Tz actuator with sliding V-shaped wedge

A focus on the "Wedge Tz actuator "



6. Anti-rotation system
7. Linear guide rail of the Tx stage*
8. Ball from a ball-bearing
9. Sliding wedge with tapered surface Ra0.4 Material : Bronze PAN
10. Sliding wedge with tapered surface Ra0.4 Material : AISI 304
11. Linear guide Schneeberger NK6* with needles
12. Actuator composed of a geared stepper motor (400ppr, ratio 1/20) and a ball-screw (Ø8, pitch 1mm)

Kinematic schema of the tripod



Control parameters and strategy

$$Tz1 = \frac{1}{\tan(\alpha)}[Tz - a\sin(Ry)] - b(1 - \cos(Ry))$$
$$Tz2 = \frac{-1}{\tan(\alpha)}[Tz + (\sin(-Rx)) \cdot (\cos(Ry))^2 \cdot r] - Dc$$
$$Tz3 = \frac{1}{\tan(\alpha)}[Tz + (\sin(-Rx)) \cdot (\cos(Ry))^2 \cdot r] - Dc$$

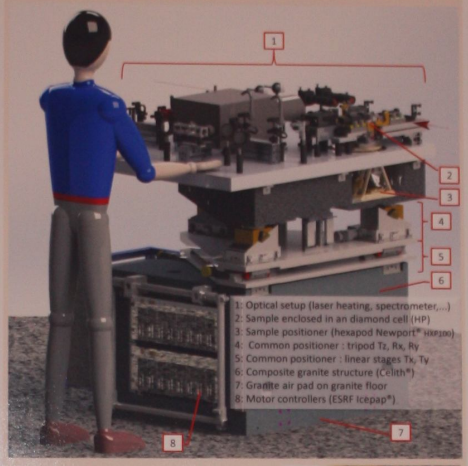
$$r = \frac{c}{\frac{\cos(Ry)}{\cos(Rx)}^2 + (\sin(Rx))^2} \qquad Dc = c - r \cdot \cos(Rx)$$

$$Rx_m = \tan^{-1}\left(\frac{M3-M2}{100}\right)_{mm} \qquad Ry_m = \tan^{-1}\left[\frac{\left(\frac{M2+M3}{2}-M1\right)}{50}\right]_{mm} \qquad Tz_m = \frac{M2+M3}{2}$$

Tz: Z absolute position of the upper table (± 14mm maximum)
Tz1,Tz2,Tz3 : Absolute position of each horizontal linear stage (*Schneeberger NK6* motorised linear stages) which actuates a wedge
α : angles of the wedges relative to the horizontal plane (25deg)
Rx, Ry : absolute angles of the upper table (position des axes, voir figure 1), range ± 2.5 deg (Ry limited according to Tz position). The coordinate system is fixed; consequently Rx and Ry are defined to stay in a horizontal plane.
Dc : compensation of wedges parasitic movements induced by rotations
r : radius of the trajectory induced by the fixed coordinate system (elliptical trajectory with Rx and Ry ≠ 0)
a,b,c : geometrical dimensions of this positioning unit
M1, M2, M3 : digital length gauges positions
Rx_m, Ry_m : angles calculated with the measured values of the length gauges M1, M2, M3

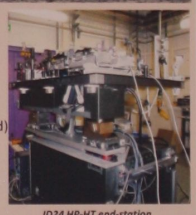
In order to reach the positioning accuracy and repeatability requirements, the target positions of the Tzi actuators are calculated from the Rx_m, Ry_m and Tz_m values. As the device controlling this system was not able to perform a real closed loop with the digital length gauges, we develop some specific macros permitting an one-off and iterative close loop at each movements requests.

End-station overview



DISTINCTIVE FEATURES OF THIS END-STATION

- Energy Dispersive X-ray Absorption Spectroscopy (EDXAS)
  - High temperature : 4000K and over
  - High pressure : 200GPa
  - Scanning resolution : up to 1µm
  - The sample positioning unit (hexapod) is used to position the sample into the laser beam.
  - Overall size : 800x1000x1200mm
  - Total weight : 1300Kg



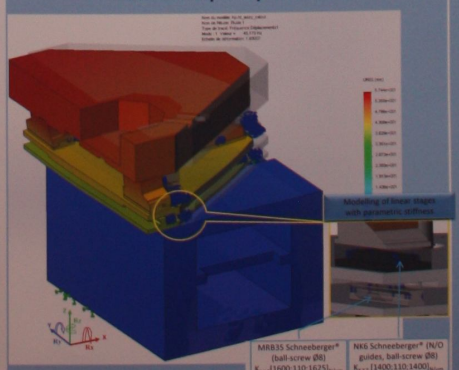
ID24 HP-HT end-station

COMMON POSITIONING UNIT

- Tz-Rx-Ry : a tripod composed of 3 Tz actuators and a central ball bushing guide:
  - Actuators specially designed for this application for a maximum stiffness
- Tx-Ty : 2 linear stages with high stiffness linear stages (crossed roller bearings)
- Reasonable cost : ~56k€ (without motor controllers)

The 5 axis of the common positioning unit

Natural frequency calculation



Modelisation with Solidworks Simulation 2010®

1st Natural frequency calculated at 45 Hz, which is the displacement in the direction X of the common positioning unit relative to the base. This vibration mode is linked to the axial stiffness of the ball-screw of the Tx stage.

Motions specifications and characterisation

Specifications for the sample positioning stages / laser beam

Axis name	Direction	Range (±)	Repeatability	Resolution (MIM)
SRx	θX	45°	< 0.01"	0.1"
SRy	θY	15°	< 0.01"	0.1"
SRz	θZ	20°	< 0.01"	0.1"
Stx	TX	10mm	< 2 µm	2 µm
Sty	TY	10mm	< 2 µm	2 µm
Stz	TZ	10mm	< 2 µm	2 µm

Weight to hold up : maximum 8 kg.
The experiment required a positioning stability of ±1µm over several hours (temperature stability of the room : ±0.5 °C).

PEL* results (HXP100)

Repeat. bi-dir.	MIM
0.0001°	/
0.0004°	/
0.001°	/
1.9 µm	0.5 µm
1.8µm	0.5 µm
1.5 µm	0.2 µm

*Precision Engineering Lab of the ESRF ISDD
Stability <1µm over 8hrs; ±0.1°C
Displacements with backlash routine

Positioning requirements for the common positioning unit

Axis name	Direction	Range (±)	Repeatability	Resolution (MIM)
Tx	TX	25 mm	< 100 µm	100 µm
Ty	TY	45 mm	< 1 µm	1 µm
Tz	TZ	10 mm	< 1 µm	1 µm
Rx	θX	2.5°	< 0.1°	0.1°
Ry	θY	2.5°	< 0.1°	0.1°

The experiment required a positioning stability of ±1µm over several hours

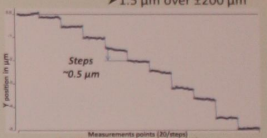
PEL results

Repeat. uni/bi-dir.	MIM
/	/
0.9/ 3.5 µm	0.5 µm
See comments	0.3 µm*
/	/
/	/

Stability not measured

Additional measurements

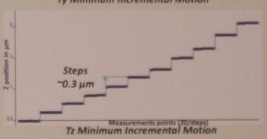
- Ty straightness according to Z axis :
  - ➢3.9 µm over ±45 mm
  - ➢1.5 µm over ±200 µm



Ty Minimum Incremental Motion

Measurement setups with a HP interferometer - PEL Team

Ty measurement setup for MIM and linear positioning at the sample location



Tz Minimum Incremental Motion

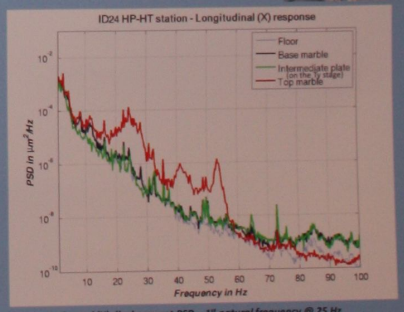
Tz measurement setup for MIM and linear positioning at the sample location

Tz measurements – Analyse

- The MIM seems lower than expected (0.3 µm instead of 1µm) but the repeatability of the steps is bad.
- Despite of the positioning control optimisation with the control loop associated to the length gauges (see left part of the poster), the positioning is not repeatable. Investigations are operating currently.

Detailed vibration measurements

Measurement Setup
➢Sensors : Geophones L4-C
sensor noise < 0.08nm (RMS) < $d_{RMS\text{-}ESRF\text{-}Site}$/1000
➢Data acquisition systems : OROS RefTek®
➢9 measurement locations
➢Measurement bandwidth : 1 to 100 Hz



Horizontal (X) displacement PSD – 1st natural frequency @ 25 Hz

The first mode is measured around 25 Hz in the X direction and the modal deformation is a global displacement of the tripod stage (as predicted with the simulation).
The gap in frequency with the simulation results could be explained on one hand by the difficulty to model, with Solidworks Simulation®, interfaces with open degrees of freedom like ball-joints or sliding wedges, and on the other hand the reliability of the stiffness settings.
However, this first mode show a lack of stiffness due mainly to the use of Ø8 ball-screws to drive all the linear stages. We made this compromise for components availability reasons, with the possibility to upgrade it later.
However, the amplifications of displacements levels are reasonable and the specified objective is reached (relative movements < 1µm peak-to-peak).
The first mode in the Z direction is higher than 100 Hz, which is reasonably good considering a 5-axis system with a moving mass of about 350 Kg.

	X	Y	Z
Floor	0.54	0.54	1.60
Base in composite granite	0.55	0.58	1.51
On the Ty stage	0.55	0.55	/
On the top of the tripod table	0.71	0.56	1.48
Max. differential tripod/ floor	0.17	0.02	0.12

Displacements peak to peak in µm in the range 0-100 Hz

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